Improved Source Term Specification Improved Evolutionary Characteristics of Directional Spectra

Donald T. Resio
University of North Florida
1 UNF Drive
Jacksonville, FL 32224-7699
phone: (904) 620-2695 fax: (904) 620-2385 email: don.resio@unf.edu

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LONG-TERM GOALS

(a) To formulate an accurate, efficient, computational model for 4-wave interactions in order to simulate the detailed shape characteristics of directional spectra produced by nonlinear momentum, energy and action fluxes in all stages of wave generation in depths from deep to shallow water.

(b) To develop improved source terms for wind input and wave breaking in phase-averaged models that incorporate the effects of phase-dependent attributes within waves and the boundary-layer flow above them.

(c) Numerically investigate the capability of the new source terms for nonlinear interactions, wind input and wave breaking to capture the details of spectral shape in detailed-balance (i.e. third generation) wave models.

(d) Determine situations in which the wave generation mechanisms in this new physics paradigm would differ markedly from existing models such as WAVEWATCH^{TM} (WW3) and SWAN for realistic wave conditions.

(e) Test the new source terms within a simple model in terms of their ability to reproduce detailed characteristics of directional spectra (energy levels within the equilibrium, spectral peakedness, and frequency-dependent directional distribution) that are consistent with recent published studies.

OBJECTIVES

For this reporting period:

1) Development of the TSA version which reduces its run time to a level comparable to the DIA while maintaining accuracies comparable to the Full Boltzmann Integral (FBI) for wave-wave interactions.

2) Develop phase-dependent computer codes for examining the expected phase-correlated inputs into surface waves in a random sea.

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3) Develop a wave-breaking source term consistent with the concepts of Irisov and Voronovich (2010) and implement in a wave model.

4) Conduct standard tests including duration- and fetch-limited wave growth tests for early versions of the new set of source terms.

APPROACH

Since we are attempting to investigate the capability of detailed-balance (third-generation) models to produce details of directional spectra, we need to start by establishing a set of objective metrics for model testing. In parallel with the development of the metrics the theoretical foundation for the phase-dependent source terms will be undertaken, along with the effort to improve the performance of the TSA (Resio and Perrie, 2008; Perrie and Resio, 2009) performance. Once these parts are all in place, we will exercise a simple model for duration-, fetch-limited, and turning-wind cases.

1) **Objective detailed-balance metrics.** Using published data on the spectral equilibrium range (Resio *et al.*, 2004; Long and Resio, 2007), spectral peakedness (Long and Resio, 2007) and directional spreading (Ewans, 1998, Wang and Hwang, 2001; Resio *et al.*, 2011), we will establish an *a priori* set of metrics for a model's performance in terms of its capability to reproduce detailed characteristics of directional spectra. Current models such as WW3 and SWAN will be evaluated in terms of their ability to reproduce these directional characteristics in order to establish a baseline for comparisons of results using the source terms developed under this project. This activity is done by Resio (UNF), Perrie (BIO), and Toulany (BIO).

2) **New wind input and wave breaking source terms.** New wind input and spectral dissipation source terms will be developed which incorporate information from all of the phases of the waves into a time varying water surface. The correlations between the individual waves on the water surface will form the basis for the input of wind energy into the wave field, rather than assuming all spectral components are free to interact with the overlying wind field independently. This differs significantly from the concept within today's phase-averaged models which assume that the spectral components are all free to interact independently with the overlying winds. In a similar vein, recent work by Irisov and Voronovich (2010) indicate that the estimation of wave breaking must consider the superposed effects of all of the waves in the wave field and tend to act in a concentrated fashion on waves at frequencies higher than the frequency of the spectral peak. This also differs from existing wave models in which the dissipation source term tends to attain its maximum value in the region of the spectral peak (Alves and Banner, 2003). This activity is done by Resio (UNF) and Aslan (UNF).

3) **Improving the efficiency of the TSA.** Initial indications included in recent testing are that TSA runs about 73 – 200 times faster than the FBI, while maintaining good agreement between them. It is believed that some modifications to the integration scheme can introduce a speed increase of about a factor of 10 – 15, without any significant loss of agreement with the FBI. This will make the TSA run times comparable to the DIA, which will help avoid potential problems with implementation of the code within operational models. This activity is done by Resio (UNF), Bender (UNF), Perrie (BIO), and Toulany (BIO).

4) **Tests of source term performance in simplified model.** Since existing operational models typically have constraints on spectral shape contained within them, we will implement the source terms

here within a simple model that does not artificially constrain the source-term integration. Model tests will include fetch-limited and duration limited cases up through full development, along with turning wind cases. The model results will be compared to the standard energy and peak frequency relationships plus the objective detailed characteristics determined in (1) above. This activity is done by Resio (UNF), Long (USACE), and Perrie (BIO).

WORK COMPLETED

The project is moving ahead on schedule following its start-up in January of 2012.

1) **Development of metrics.** This effort required a search for reliable field data sets; however, we have now assimilated the characteristics of all data sets into some common metrics for comparison to the results generated by the source terms developed in this study. As part of this, we have established a set of functions which link the characteristics of the observations to simple parameters such as wave age for the case of the duration-limited and fetch-limited cases.
2) **Improved efficiency of the TSA.** With the help of Charles Long, recently retired from the US Army Corps of Engineers, we began with an extensive test of the run-time and error characteristics of the TSA compared to the FBI, including the effects of discretization of the pre-calculated matrix terms noted in Resio *et al.* (2008). Figure 1 from these numerical investigations show that the TSA is already capable of achieving an increase in run speed of a factor of about 200 over the FBI, while maintaining good accuracy in its approximation. Thus, believe that it will be possible to reach our ultimate goal of a speed-up of 1000 to 2500 times faster than the FBI.
3) **New wind input and wave dissipation source terms.** The gist of the new wind input source term is the definition of moving water surface which is utilized to define the Miles class of wind input. A zero-crossing analysis of the water surface first separates the time-space domain into moving regions of pressure perturbations linked to the wind passing over this surface. The correlation between a specific spectral (frequency-direction) component represents the relative wind input into that spectral component. Our early results show a much more peaked distribution of wind input in frequency with a maximum value slightly above the frequency of the spectral peak and a much more peaked distribution of wind input with respect to direction centered on the direction of the wind. This is consistent with our heuristic concepts of wave generation and deviates substantially from wind inputs used in conventional operational wave models today.
4) **Implementation of our new source term set into a simple model.** We have just begun the implementation of our source terms into a simple model in order to avoid issues with shape constraints and integration limiters in existing operational codes. Our preliminary tests suggest that this simple model will work well for our testing. Of course, this is only meant to be the basis for development of numerically efficient operational versions of these new source terms before implementation in forecast wave models.

RESULTS

The meaningful technical results achieved in this fiscal year are:

a) Our preliminary results suggest that our results support much of the work published in the area of self-similar wave generation processes (Badulin *et al.*, 2005, 2007), which are postulated on the premise nonlinear fluxes through wave spectra are the dominant factor shaping the spectrum

during wave generation. This is also consistent with the findings of Resio *et al.* (2011) which is based on computations of nonlinear fluxes of energy and momentum through wave spectra via an exact integration of the Full Boltzmann Integral. There is almost an exact match between the directional spreading in observed spectra and the spectral form that produces a net zero divergence in fluxes of both energy and momentum. Since the new wave dissipation source term is relatively small in the region of the spectral peak, it allows the nonlinear flux term and wind term to balance in a manner which reproduces the observed self-similar behavior.

b) Tests with our new source terms have shown that our early implementations of the new source terms seem capable of simulation both the total energy growth and the detailed-balance characteristics of the wave growth.

IMPACT/APPLICATIONS

This project is concerned with returning to a detailed-balance basis for judging the performance of third-generation models. Third generation models were initially created to be able to improve the performance of spectral models in terms of the detailed aspects of the physics, but now appear to focus primarily on matching only a small set of integrated wave parameters. We feel that our new set of source terms may help fulfill the original intent of this class of models and extend our modeling accuracy into more complex situations and into improved spectral shapes which are critical to the prediction of individual wave characteristics for naval operations.

RELATED PROJECTS

There are many related efforts within the NOPP Project; however, most of these focus on using models for predictions of simple wave parameters and not for predictions of the details of the directional wave spectra. The ongoing research by Dick Yue at MIT on ‘Phase-resolved modeling of nonlinear wave fields,’ which is also sponsored by ONR, is probably the single effort that is most related to the work on the source terms of the type that has been undertaken on this project.

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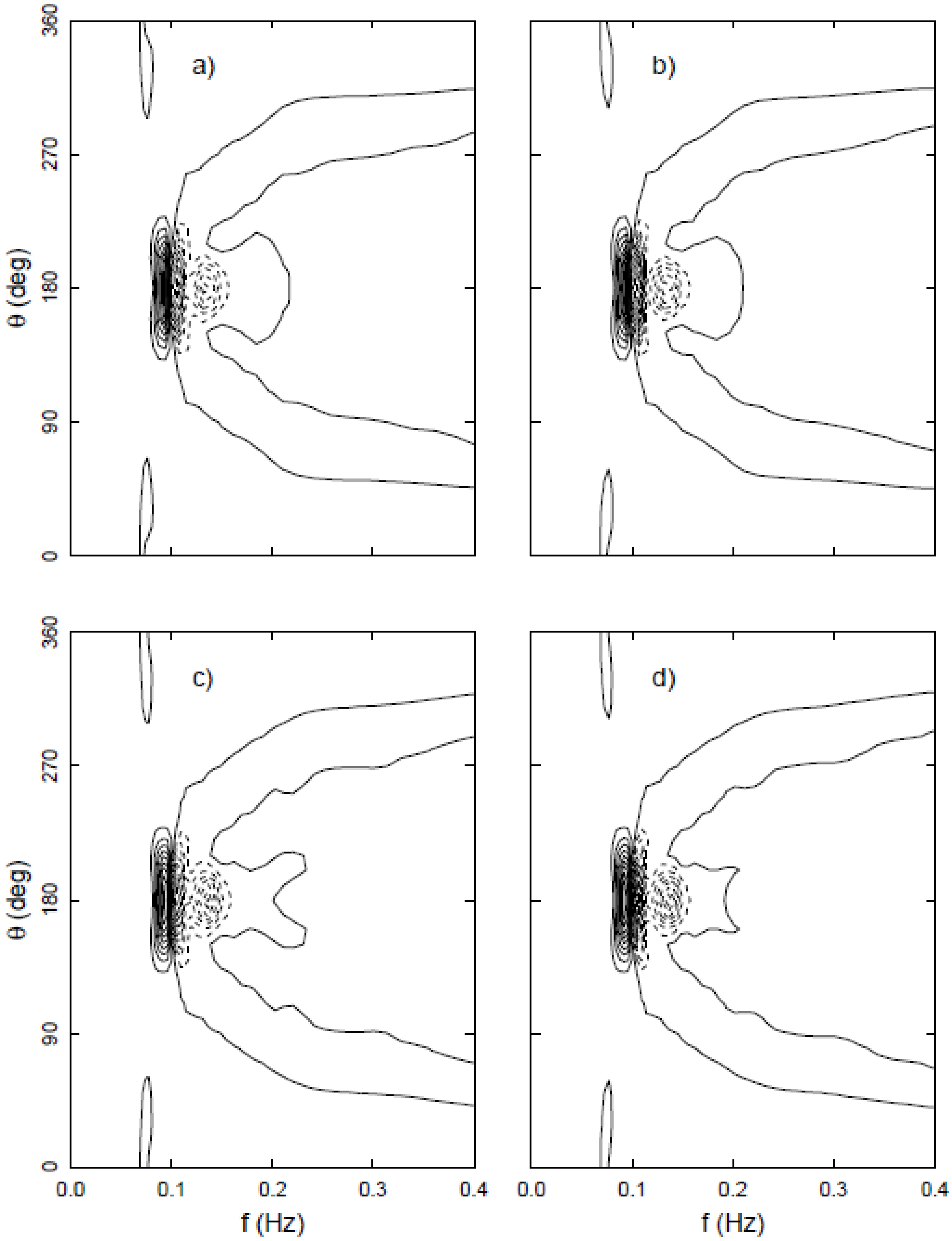

Figure 1. Directional nonlinear source term for an input spectrum with a directional distribution function based on equations in Appendix A of Resio et al. (2011). These results show good agreement of directional distributions of $S_{nl}(f,\theta)$ between TSA and FBI computations when input and template spectral directional distributions are not necessarily identical.